Effort to Accelerate MBSE Adoption and Usage at JSC

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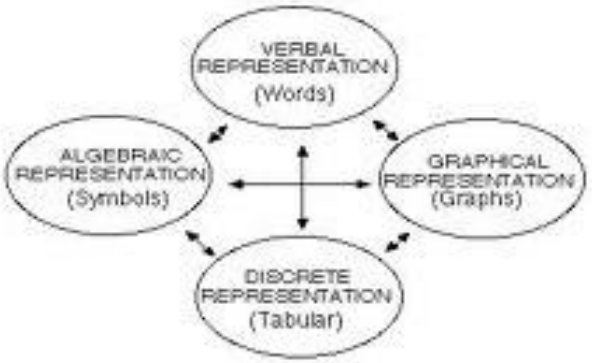
Agenda

- **Motivation**
- **Challenges to MBSE Adoption**
- **Effort to Facilitate MBSE Adoption**
  - Approaches to Address Challenges
  - Modeling Methods
  - Reusable Model Elements
  - Toolset
  - Project Case Studies
- **Conclusion**

Motivation Catalyst

- **Spacecraft design and operation stakeholders are creating models/artifacts of the same system with different processes, tools, and representations.**
- **These oft uncoordinated approaches create locally successful products but also create a communication barrier among the various stakeholders (the "Tower of Babel" Effect).**

- **The same information is captured multiple times, in multiple places, with multiple representations, creating a maintenance challenge.**



MBSE at JSC

- **JSC has applied MBSE using SysML to a number of advanced projects since 2009**
- **Objective of MBSE is to reduce product cycle time, improve product quality, and product maintainability**
- **MBSE provides a formal understanding of the features and structure of a product**

Challenges to MBSE Adoption

1. Force of inertia impedes MBSE Adoption

- High risk environment (space projects) tends to gravitate toward conservative engineering
- Over valuation of current approaches to achieve success
- Perception that potential long term benefits are outweighed by short term risks
- Stories, real or perceived, of undelivered promises of MBSE are often presented to challenge the move

2. Additional Costs & Efforts Associated with MBSE Adoption

- Adopting MBSE requires additional costs
  - Buying enough tool licenses & trainings
- Additional effort to build the models
  - Learning a tool
  - Time consuming effort to build the model from scratch
  - Starting the model development can be daunting
  - Limited readily available library of reusable system models
  - Extra costs associated with early adoption for small and short duration projects

Challenges to MBSE Adoption

3. Difficulty in getting started with MBSE

- No roadmap to follow the best practices required for successful adoption
- Multiple issues need to be resolved even at the start of a project
  - What training is needed for whom?
  - What is the right mix of team skills needed?
  - What modeling methodology to use?
  - What tool to use?
  - Are there some guidelines or a process to follow?
- SysML language semantic is very rich and complex
  - Difficult to decide which modeling technique is appropriate for the project
  - After classroom training sessions, modelers still do not know how to begin
  - No defined process to guide modelers in the development of the SysML model representing the target system
- MBSE is first and foremost Systems Engineering
- NASA Systems Engineering Handbook does not provide much guidance regarding MBSE

Approaches to offset “force of inertia”

- **Alleviate the perception of increased risks using targeted presentations focused on**
  - Benefits of using MBSE
  - Availability of the models tools
  - Successful project experiences
  - Emphasize the value proposition
  - Provide evidence on how the project can benefit by adopting MBSE
- **Identify a project champion**
  - JSC SysML User’s Group help champion the change
  - Systems Engineers are the primary target audience.
- **Provide tools and concrete added value examples that benefit SME daily activities**
  - SME does not have direct responsibility for system engineering
- **Demonstrate the capability to support communication between all the project stakeholders**

Approaches to address “Additional Costs and Efforts” for MBSE Adoption

- **Requires a combination of institutional and project support for training software tool licenses**

- **Provide for a team of expert modelers that can be matrixed into the project for successful MBSE adoption**
  - Experienced Modeler is partner with the System Engineers to support adoption of modeling practices and tools
  - Project Mentor is part of the project team and be involved in the system integration and design

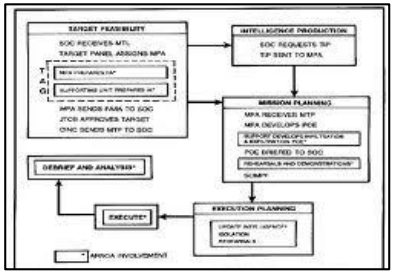
Approaches to address “how to get started?”

- **“Model with a Purpose” is an important concept for successful adoption**
  - Helps clearly define the goal and objective of the project
  - Helps manage expectation with the stakeholders
  - Helps narrowing down modeling methods
  - Helps identify the most appropriate modeling diagrams

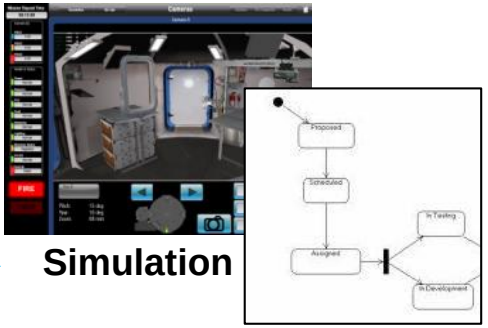
- **JSC System Modeling Team (JSMT) focused on**
  - Developing modeling methods
  - Developing tools to generate project artifacts
  - Providing modeling and tool guidelines
  - Providing exemplary reference models
  - Providing reusable model component

Artifacts by Multiple Stakeholders

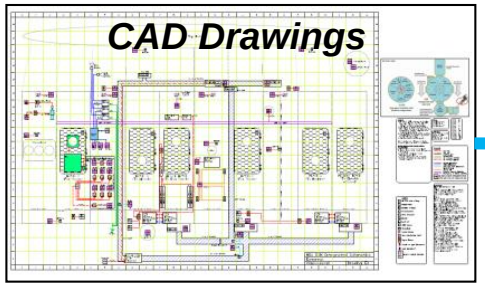
Telemetry and Command

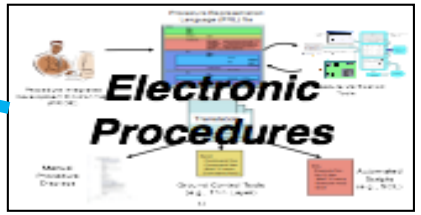


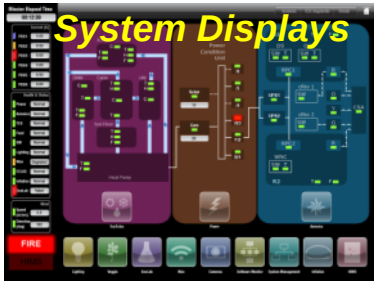
Mission Operation Planning

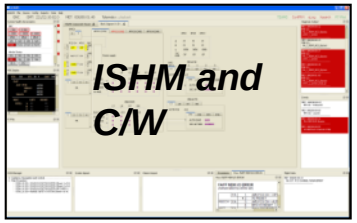


Simulation



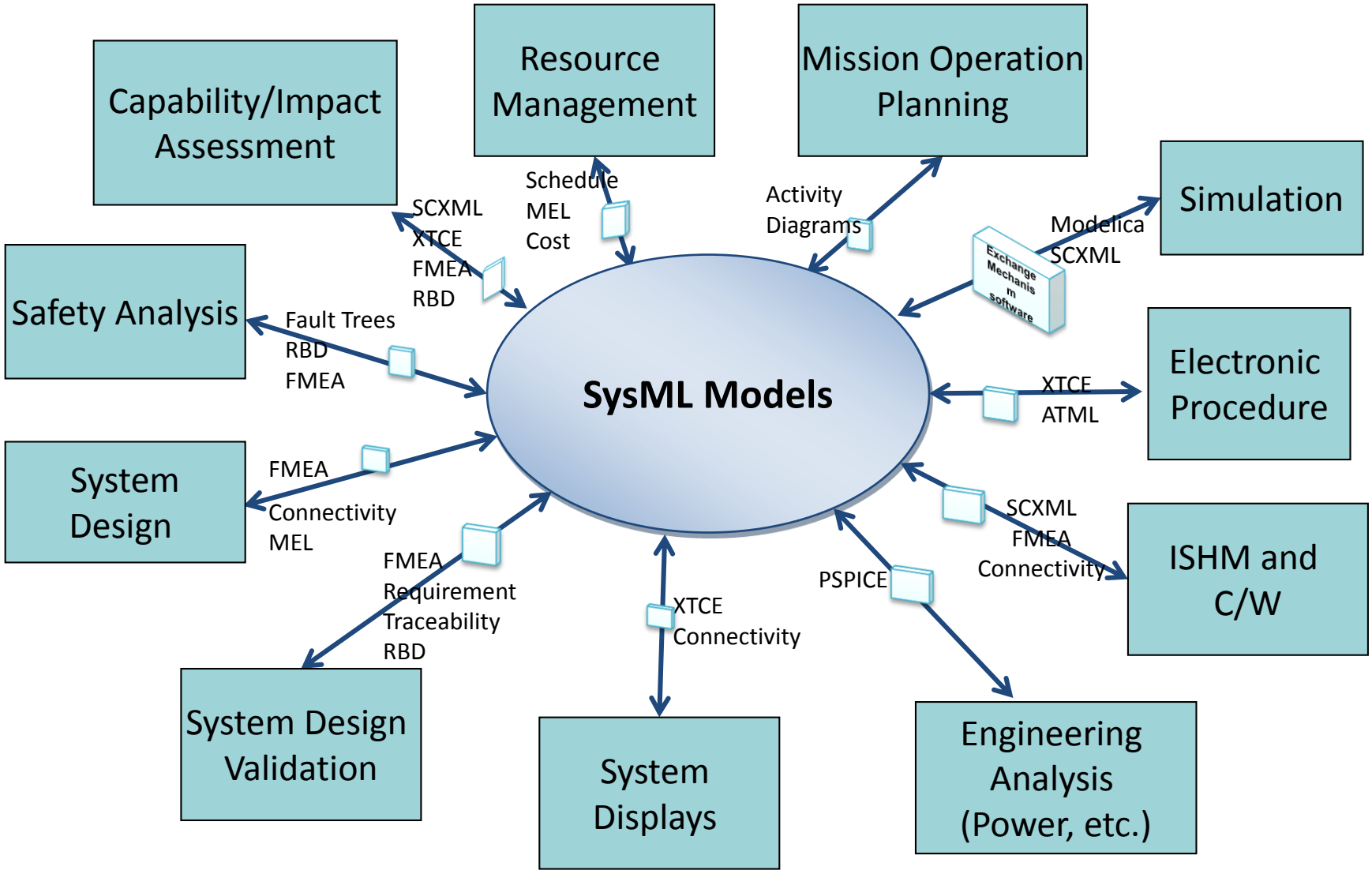






Uses of System Models

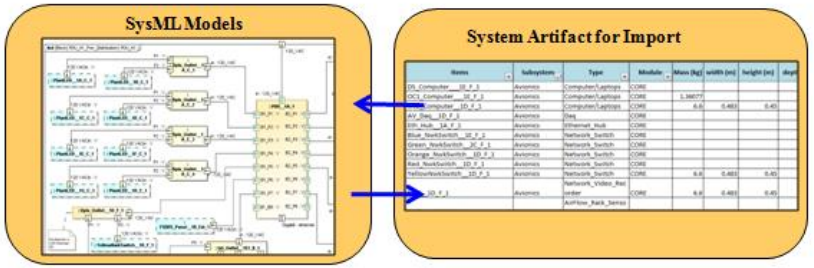
Model once and Use many times



Experience with SysML Modeling and Tool Set Development

- **Developed a modeling methodology**
- **Developed SysML Models for Multiple NASA Projects:**
  - *Deep Space Habitat (DSH)/ Habitat Demonstration Unit (HDU)*
  - *Exploration Augmentation Module (EAM)*
  - *Integrated Power and Avionics System (IPAS)*
  - *Cascade Distiller System (CDS) Life Support System (LSS)*
  - *Human Exploration Testbed Integration and Analysis (HESTIA)*
  - *Advanced Exploration System - Modular Power Systems (AMPS)*
  - *Orion*
- **Developed SysML Library Repository**
  - *Collection of SysML Models*
- **Provide a suite of data exchange tools**
  - *To extract System Engineering products from the models*
  - *To build models by extracting automatically or semi automatically information from existing sources*
  - *To support Fault Management engineering*

Model Based Engineering/ SysML Data Exchange Tool Development



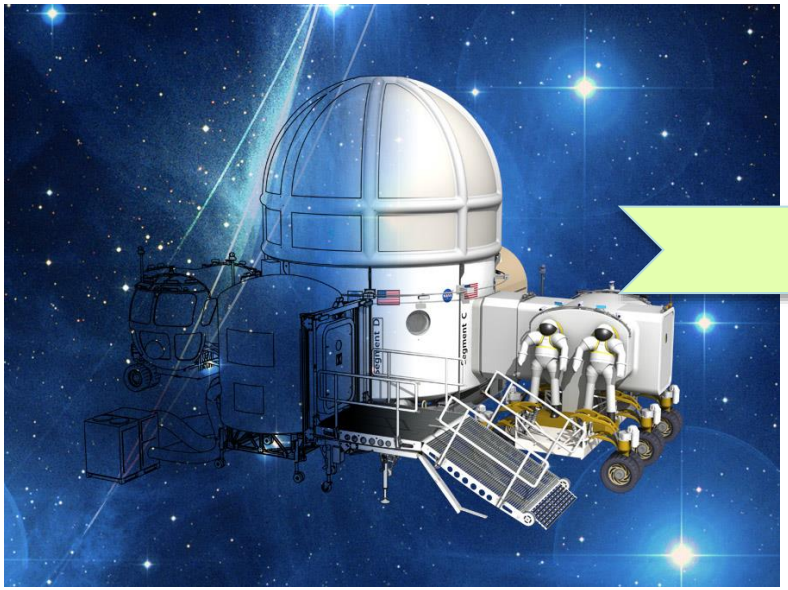
- Plug-Ins in use by NASA projects:
  1. **MEL plug-in:** Generates a Master Equipment List (MEL); mines data related to SysML block attributes and relationships
  2. **Connectivity plug-in:** Generates connectivity and conveyed information data
  3. **FSM plug-in**: Generates Finite State Machine data for use by simulator engines
  4. **XTCE plug-in:** Generates Command and Telemetry data (via XML file)
  5. **SysML Builder plug-in**: Generates SysML elements and diagrams from an Excel/CSV template (for SysML modelers and AutoCAD data extraction)
  6. **FMECA plug-in**: Generates a subset of FMECA data (failure modes and derives end effects)
  7. **FTA plug-in**: Generates Fault Tree Analysis for a selected event

♦ **Prototype Plug-Ins:**

  8. **PRA plug-in:** Traverses the behavior diagrams extracting the reliability values and compute the system reliability numbers.
  9. **UUT plug-in**: Generates ATML (Automated Test Mark-Up Language) for Unit Under Test (UUT)
  10. **Power Analysis plug-in**: Traverses connectivity to calculate total current
  11. **PSpice Netlist plug- in**: Generates P-SPICE netlist from SysML models
  12. **GUNNS/Trick plug-ins**: Generates data for the General-Use Nodal Network Solver (GUNNS) modeling software for use with NASA's Trick simulation environment
  13. **TEAMs plug-in**: Generates Failure Mode and connectivity data for import to TEAMs tool
  14. **Parametric Analyzer Plug-in:** Runs parametric analysis

Case Study 1 – HDU/DSH

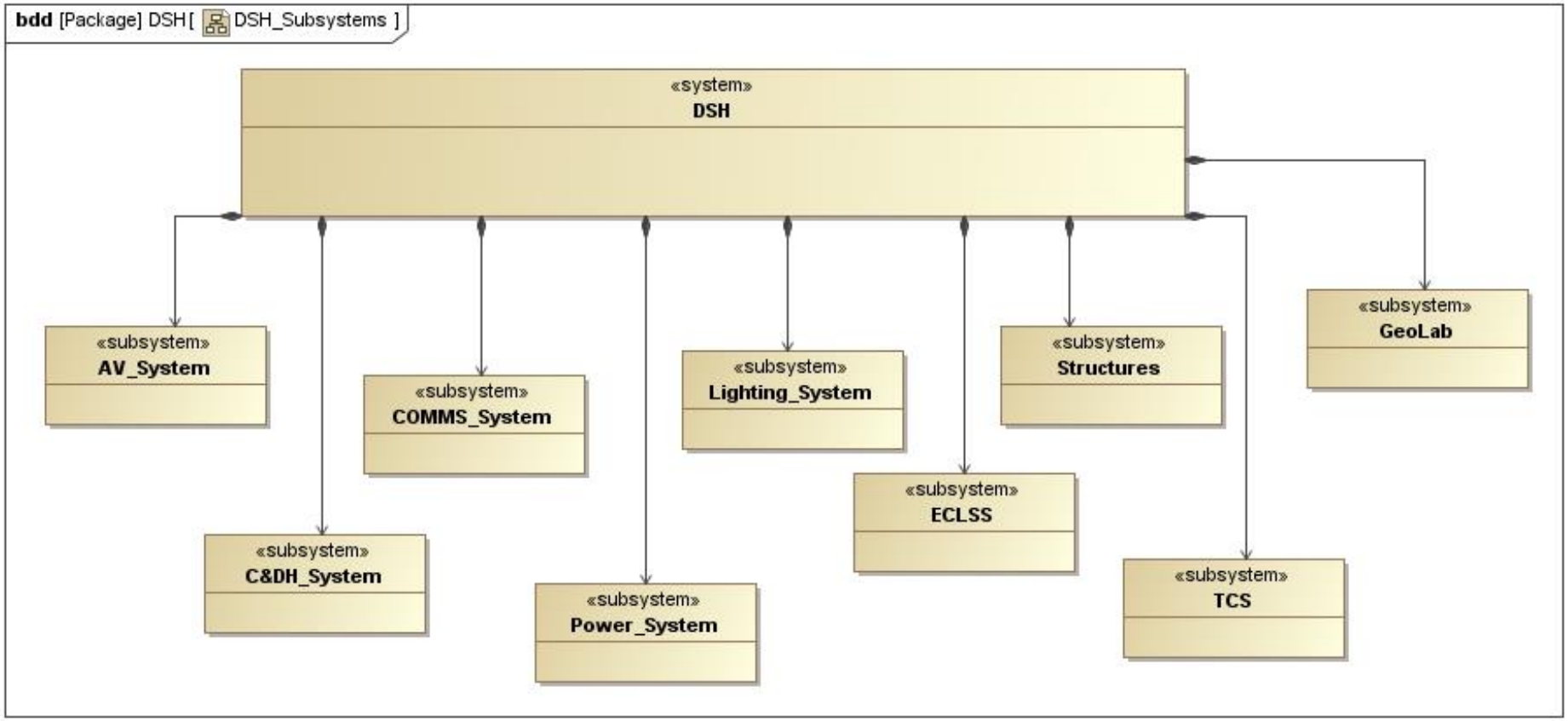
- **Multi-center Technology Investment Project started in 2010.**
- **Objectives:**
  - Evaluate and validate Lunar Surface System (LSS) Habitat Concept efficiency and effectiveness
  - Build, integrate, test, and evaluate the vertical habitat configuration utilizing developmental hardware & software



HDU/DSH Modeling and Tool Overview

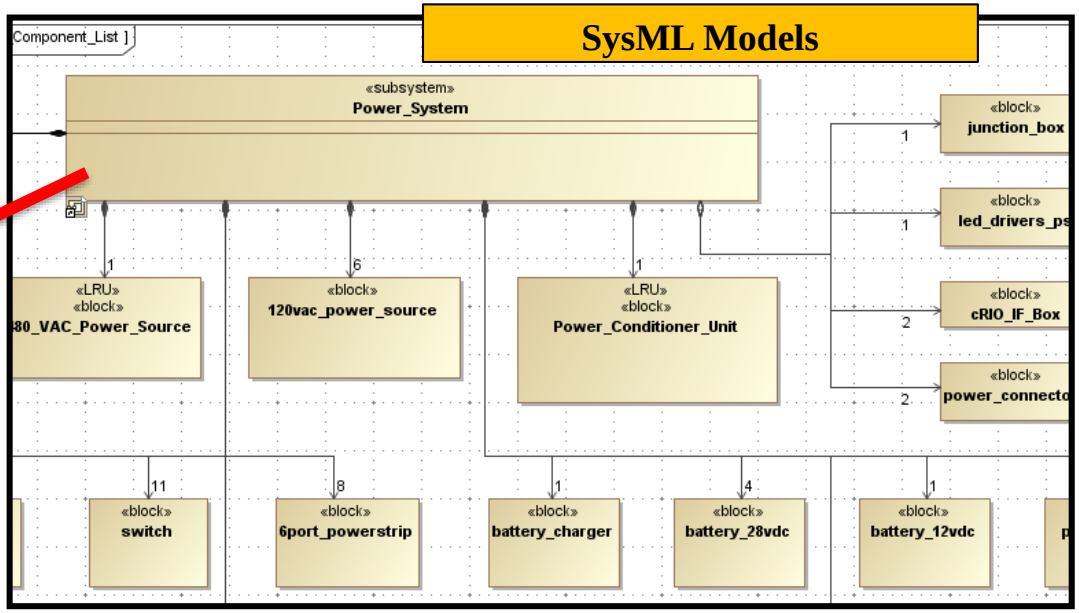
- The team's role in support of the HDU/DSH project was developing the software architecture
  - Maintaining command and telemetry dictionaries, creating crew displays, developing electronic procedures
- An initial modeling approach was developed specifically targeted to the products needed for the hardware/software integration
  - The initial target artifacts were system connectivity representation to populate crew displays and XTCE to capture Telemetry and Commands for various software applications
- Detailed SysML models of all the subsystems including a full set of structural and behavioral models were built throughout the design phase
- The model and SysML tools were used to support HDU/DSH surface operations and testing.

DSH System Model



Created tool to generate master equipment list (MEL)

SysML Models



Magic Draw Plug-Ins

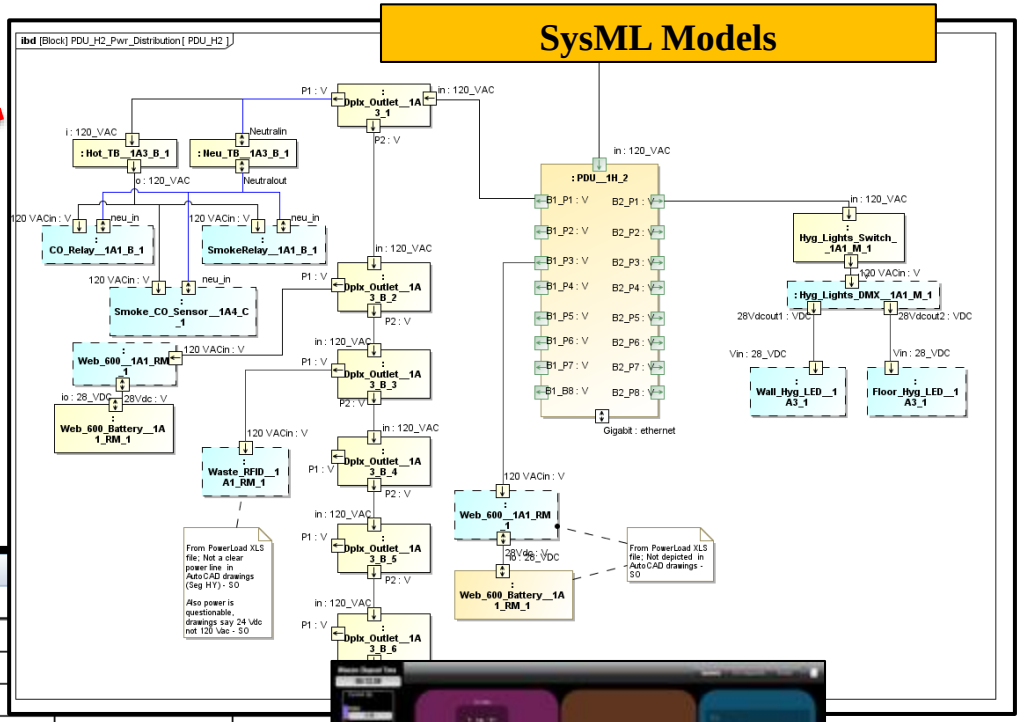
MEL

	A	B	C	D	G	H	I	J	K	L	M
1	Component Type (* = Removed Items or Test Articles)	Subsystem	Documentation	Qty	Mass (kg)	width (m)	height (m)	depth (m)	Avg Power (W)	Max Power (W)	Voltage Type
2	pdu	Power_System		6		0.114	0.4449986	0.089			
3	dplx_outlet	Power_System		47							
4	quad_outlet	Power_System		12							
5	battery_12vdc	Power_System		1		0.181	0.167	0.076			
6	battery_28vdc	Power_System		4							
7	battery_charger	Power_System		1					80		120VAC
8	poe_injector	Power_System		1							
10	6port_powerstrip	Power_System		8	1.36				60		
12	rpc	Power_System	Avionics Power Distribution Unit aka RPC	2	4.5	0.445	0.089	0.114	1	1	120 VAC
20	ups_accumetrics	Power_System	Uninterrupted Power Supply (Accumentrics)	2	19.73	0.09	0.043	0.041	140	140	120 VAC
22	120vac_to_12vdc_converter	Power_System		2							
23	120vac_to_24vdc_converter	Power_System		3							
24	variable_converter	Power_System		1	8.6	0.254	0.2032	0.1016			

Created tool to extract connectivity

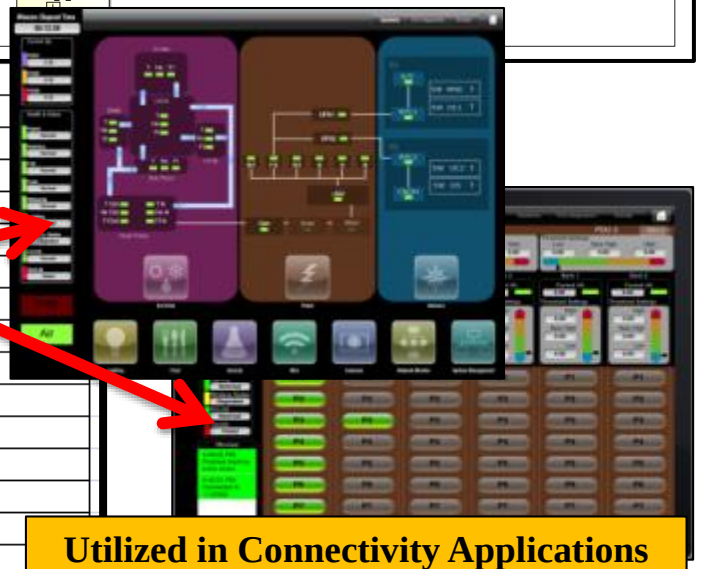
Magic Draw Plug-Ins

SysML Models



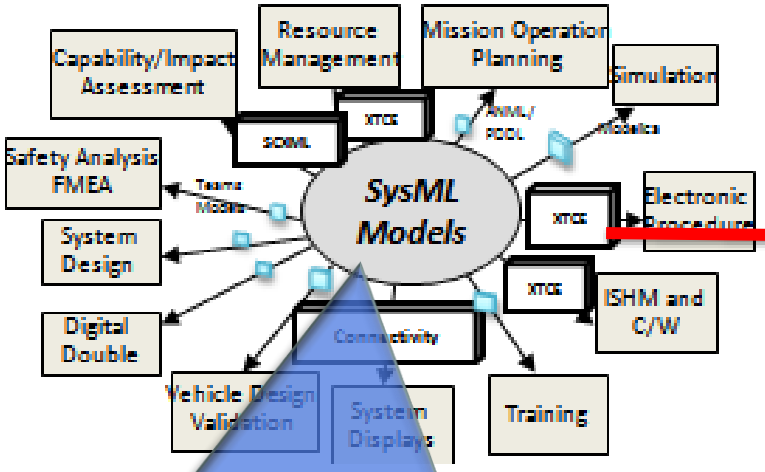
Connectivity

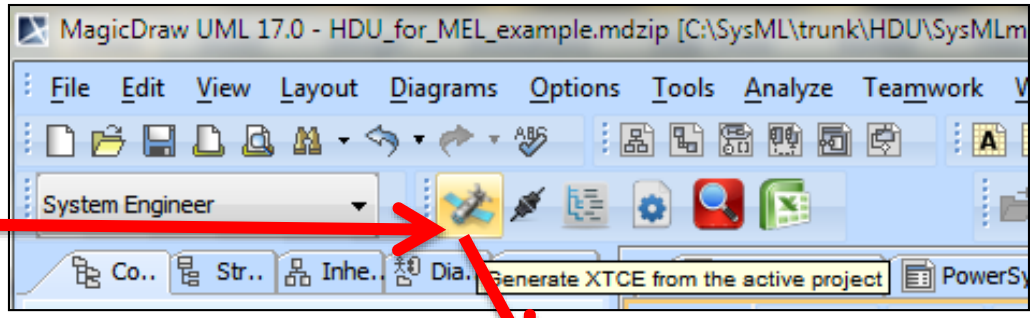
A	B	C		
source	destination	source port		
PDU__1H_1	Hot_TB__1H_B_1	B2_P3		
PDU__1A_1	Dplx_Outlet__1E2_M_1	B2_P7		
Hot_TB__1E2_1	O2Sensor__1E2_RT_1	o		
PDU__1B_2	Dplx_Outlet__1B_B_2	B1_P4	in	Power
Green_NwkSwitch__2C_F_1	Cam_VS__2C_F_1	P7	Gigabit	Data
Green_NwkSwitch__2C_F_1	Laptop__2_1	P13	1	Data
Spotlight_Switch__1A_M_2	Spotlight__1D_Ext_1		28Vdcin	Power
PDU__1A_1	Dplx_Outlet__1F_B_1	B2_P2	in	Power
Dplx_Outlet__1A3_B_5	Dplx_Outlet__1A3_B_6	P2	in	Power
Blue_NwkSwitch__1E_F_1	GB_Eth_Hub__1H_1	P14	1	Data
Hot_TB__1E2_1	CO_Relay__1E2_RM_1	o	120 VACin	Power
Dplx_Outlet__1A_C_1	PlantLED__1B_C_1	P2	120 VACin	Power
Pwr_Connector__1D_F_1	RPC__1D_F_1		1in	Power
Pwr_Connector__1D_F_1	RPC__1D_F_1		2in	Power
Signal_TB	SmokeRelay__1H_F_1	smoke		Data
Dplx_Outlet__1F_F_2	28_VDC_PS__1F_F_1	P1		Power
PDU__1A_1	Dplx_Outlet__1B_B_1	B2_P3	in	Power
Hot_TB__1H_B_1	Smoke_CO_Sensor__1D_T_1	o	120 VACin	Power
28_VDC_PS__1F_F_1	28_VDC_TB__1F_F_1	o	in	Power

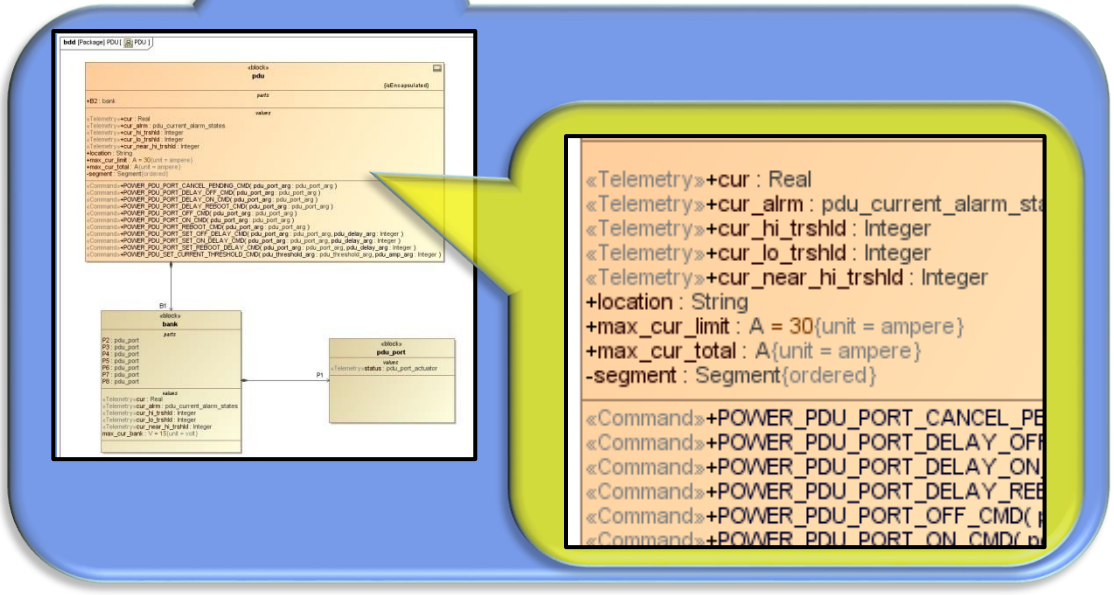


Utilized in Connectivity Applications

Created tool to extract XTCE







XML Telemetric and Command Exchange (XTCE) : OMG standard for Spacecraft T&C

```
<SpaceSystem name="RIU2">
    <AliasSet>
      <Alias alias="02" nameSpace="id"/>
      <Alias alias="020602" nameSpace="interface"/>
    </AliasSet>
    <Header classification="INTERFACE"/>
    <TelemetryMetaData>
      <ParameterSet>
        <Parameter parameterTypeRef="HUMIDITY_DEWPOINT_SENSOR"
shortDescription="GEOLAB_GB_HUMIDITY1_DEWPOINT_SENSOR"
name="020602018001">
          <ParameterProperties dataSource="telemetry">

<SystemName>CORE.GEOLAB.RIU2.HUMIDITY_DEWPOINT_SENSOR.1</System
Name>
          </ParameterProperties>
        </Parameter>
        <Parameter parameterTypeRef="VALIDITY" name="020602054001">
          <ParameterProperties dataSource="telemetry">
            <SystemName>CORE.GEOLAB.RIU2.VALIDIDY.1</SystemName>
          </ParameterProperties>
        </Parameter>
        <Parameter parameterTypeRef="HUMIDITY_PRESSURE_SENSOR"
</Parameter>
```

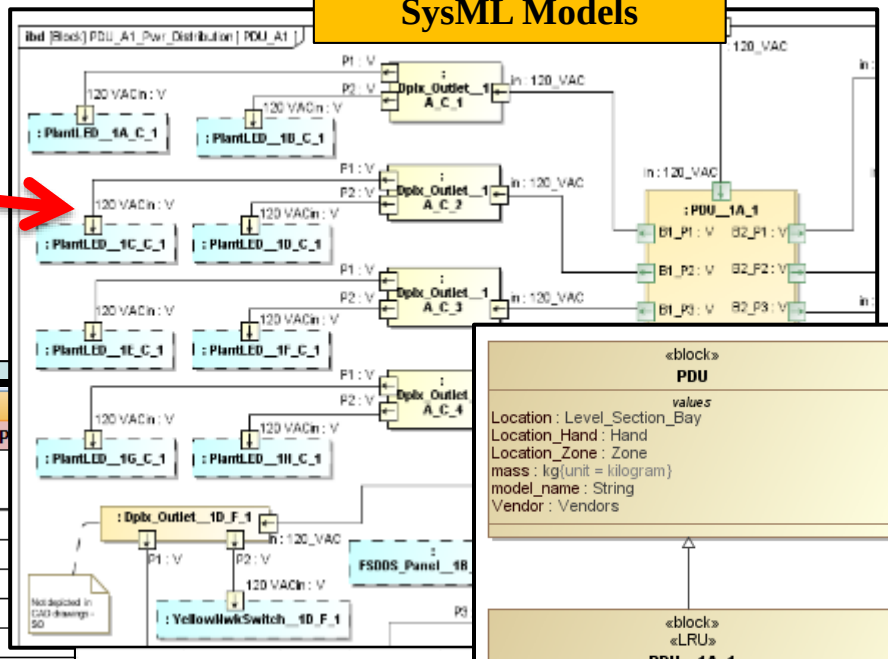
Created a tool to import data and generate SysML models

Magic Draw Plug-Ins

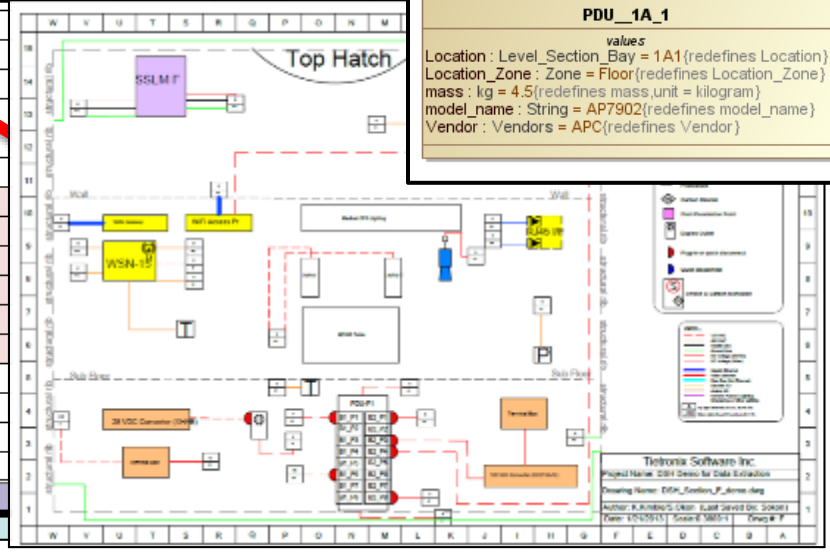
Artifacts for Import

	A	B	C	D	E	
1	BLOCK			PROP		
2	BLOCK	BASE	BLOCK EXTENSION	PROPERTY	NAME	
4	Avionics		Subsystem			
5	Power_System		Subsystem			
6	PCU					
7	pdu_with_port_test					
8	port_test					
9	B1_P1	port_test				
10	B1_P2	port_test				
11	B1_P3	port_test				
12	B2_P1	port_test				
13	B2_P2	port_test				
14	B2_P3	port_test				
15	pdu_with_port_test	port_test		Part		B1_P1
16	pdu_with_port_test	port_test		Part		B1_P2
17	pdu_with_port_test	port_test		Part		B1_P3
18	pdu_with_port_test	port_test		Part		B2_P1
19	pdu_with_port_test	port_test		Part		B2_P2
20	pdu_with_port_test	port_test		Part		B2_P3
21	tb					
22	Converter					
23	cRIO_test					
24	computer_test					
25	Power_Conditioner_Unit_1x	PCU				

SysML Models



AutoCAD to CSV Generation



Case Study 2 - Integrated Power, Avionics and Software (iPAS)

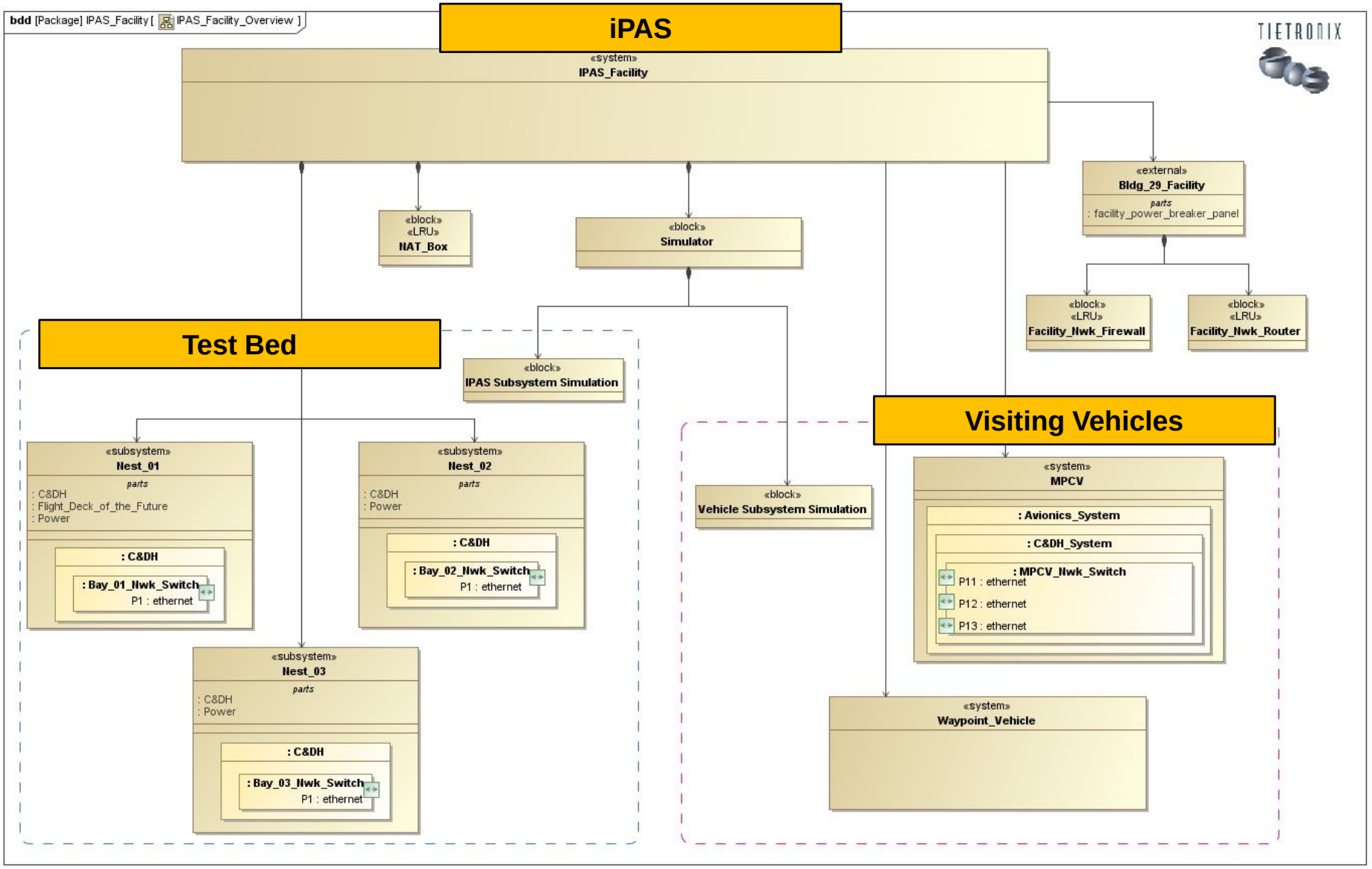
- iPAS is a testing facility focusing on the integration of visiting vehicles to test new technologies

- The import tool, built for the previous HDU project, was used to build the iPAS SysML models
  - Model included Power, Avionics, Command & Data Handling, and Propulsion systems
  - The iPAS model captured system architecture, connectivity and command and telemetry attributes

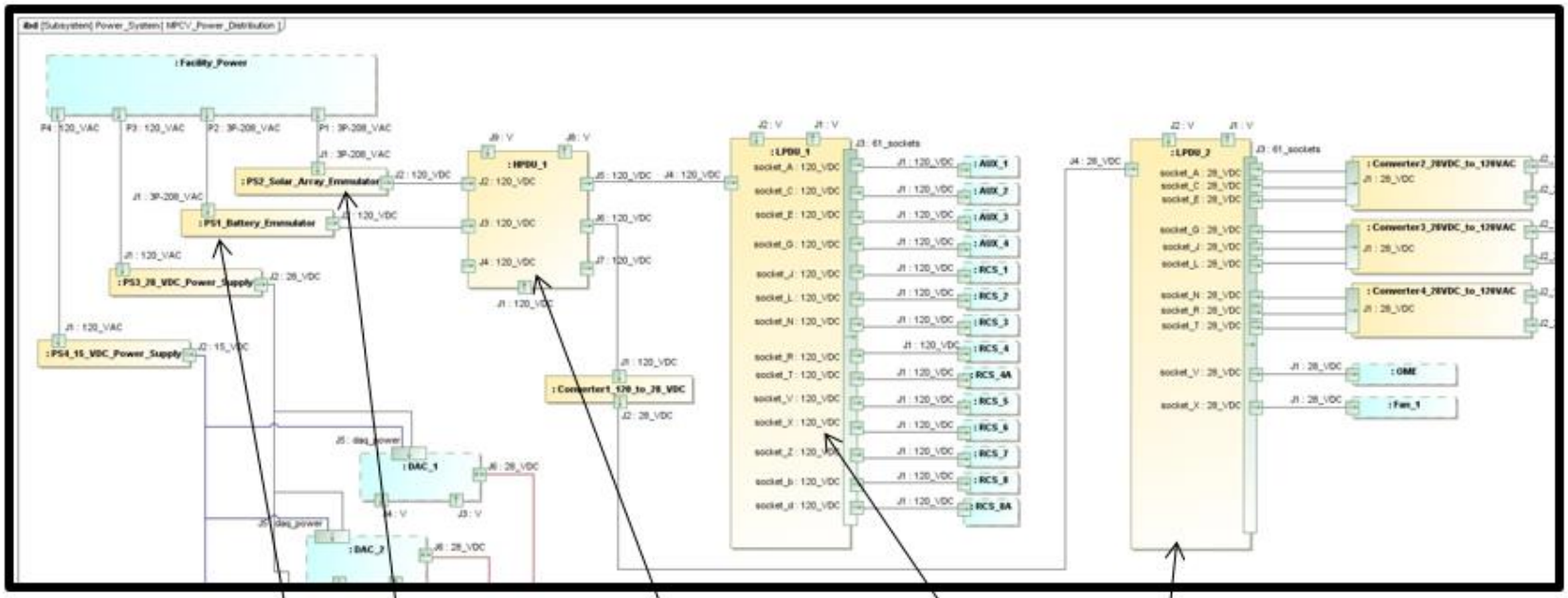
- The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.

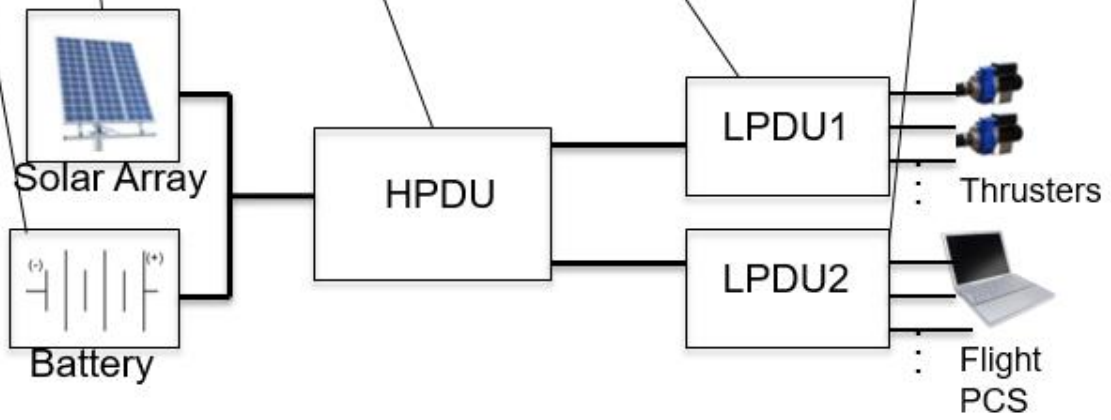
- Using the tools and established modeling method, the model development and data extraction was completed in a week.

iPAS Facility (Avionics Focus)

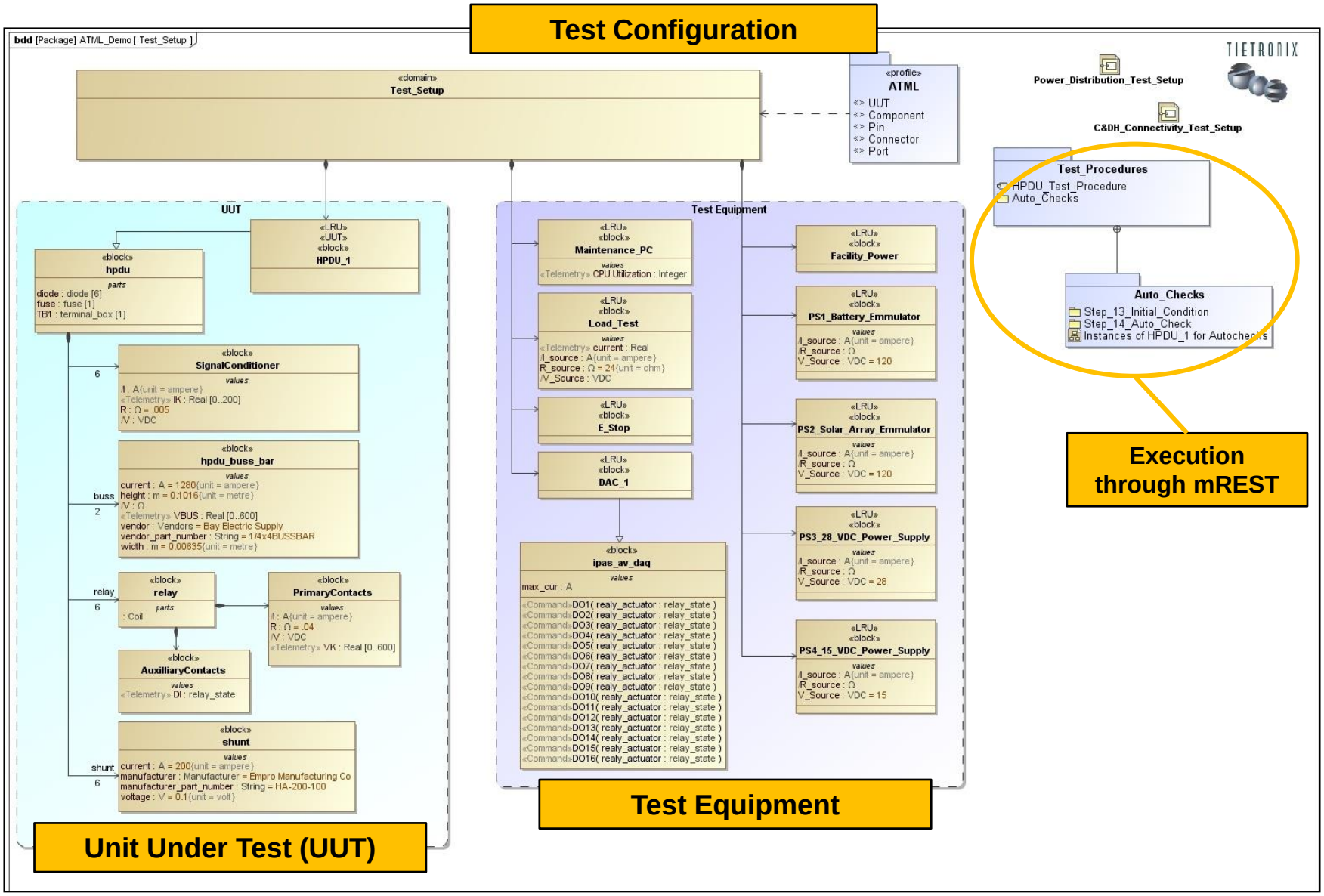


iPAS Power Distribution Model for MPCV





iPAS – Model Design for ATML and mREST



Case Study 3 – Cascade Distillation System (CDS) Life Support System

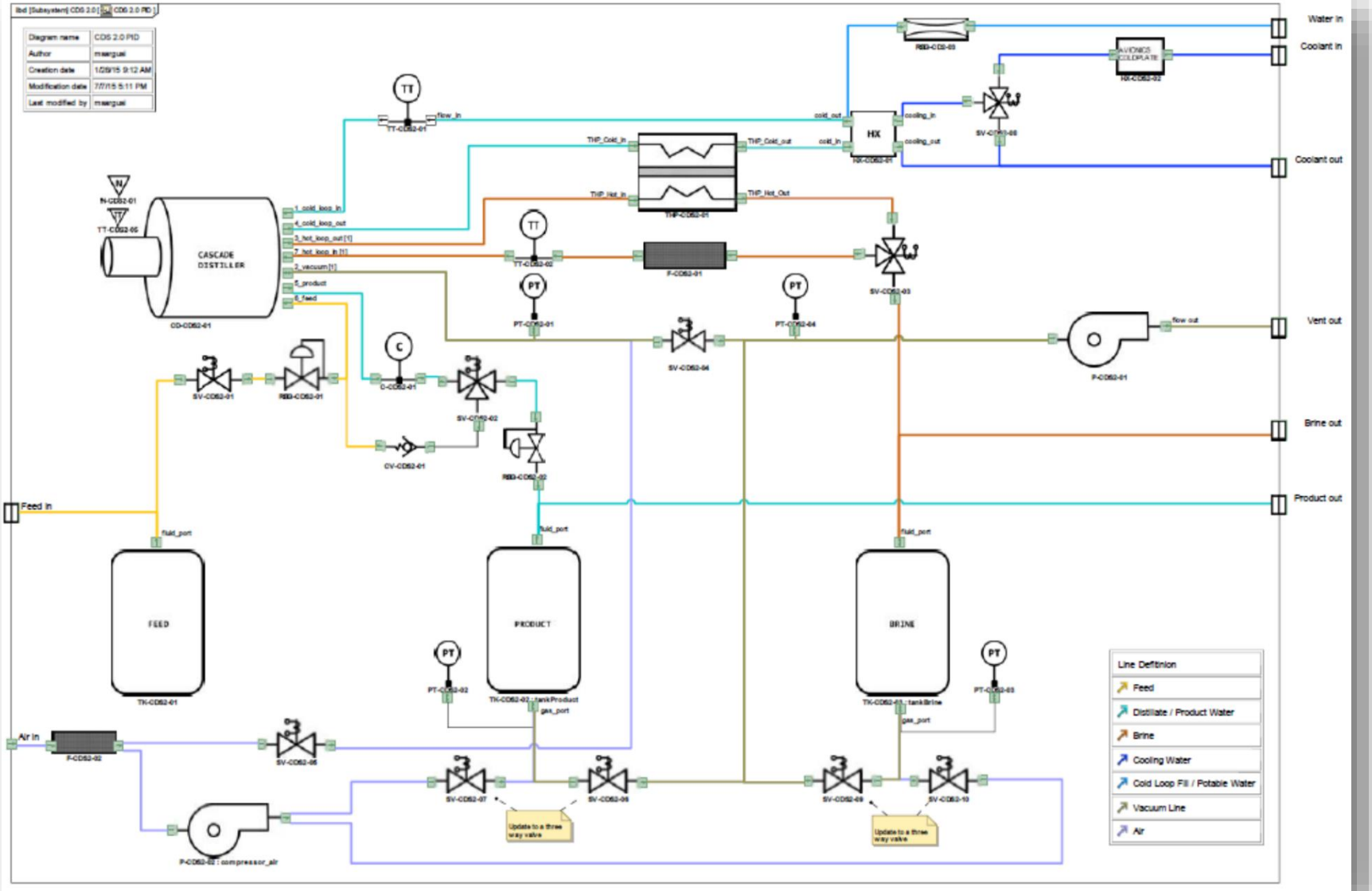
- The CDS is a water recovery system designed to support future human exploration missions beyond low earth orbit.

- The CDS system model was created using the same modeling method and tools.
  - Derived model artifacts in support of CDS system and software design
  - The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.

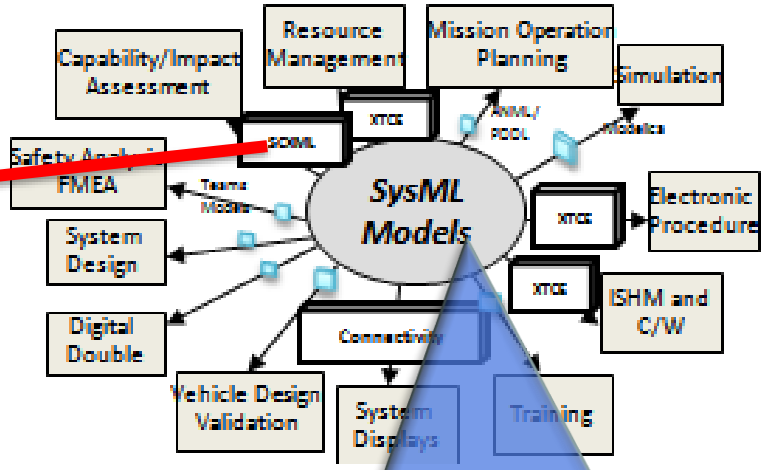
- The design utilized the Fault Management (FM) methodology to incorporate FM elements into the architecture.
  - The behavior of each component was captured in state machine models using the methodology.

- The FMECA and Fault Tree tools were used to perform a risk analysis

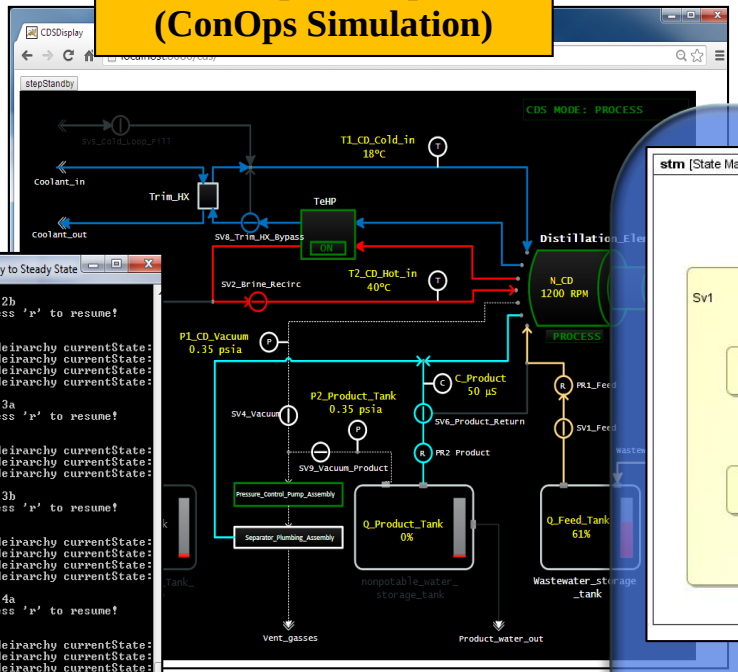
CDS SysML Schematic (Physical Architecture)

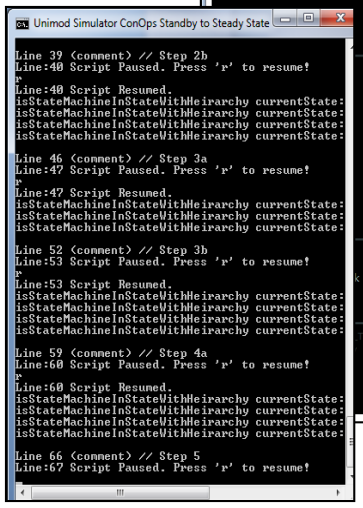


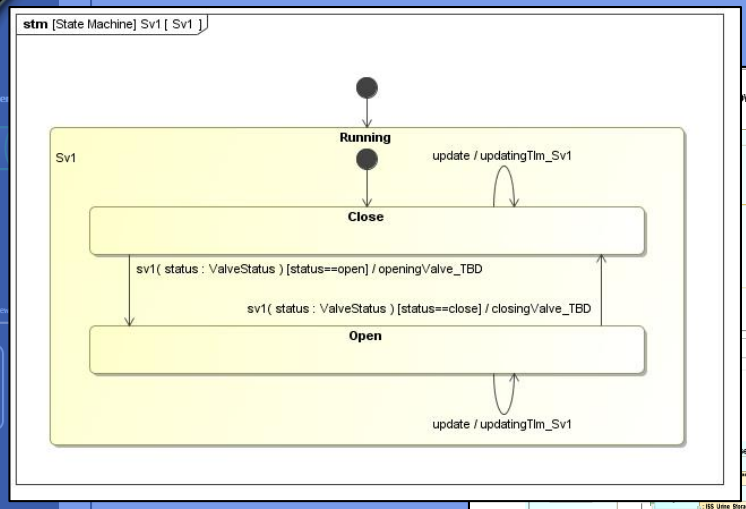
Extracted State Machine Data for ConOps and Risk Analysis

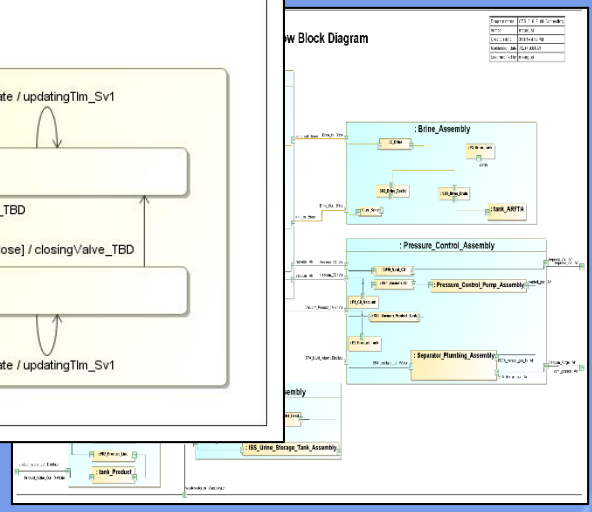


Example Output (ConOps Simulation)



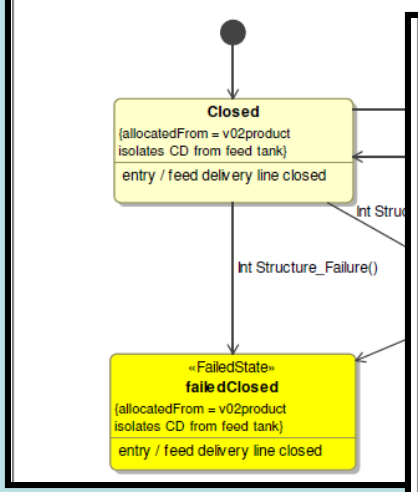


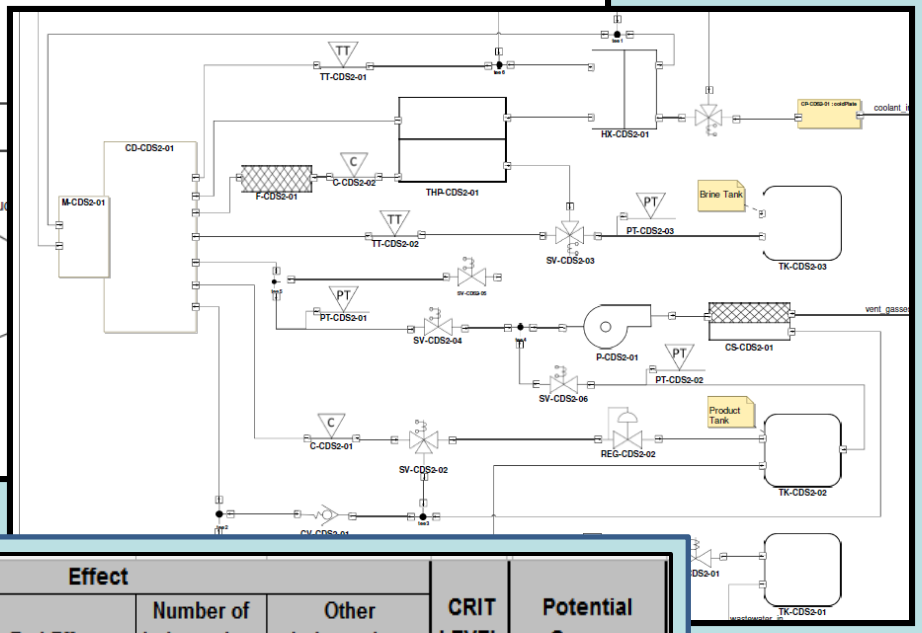




FMECA Extraction

SysML Models



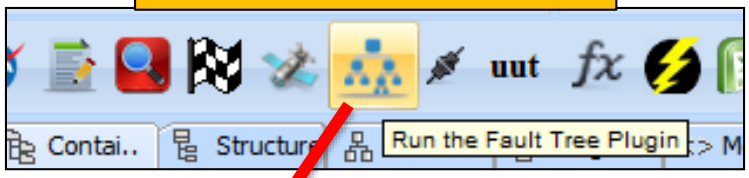


Generated FMECA Output

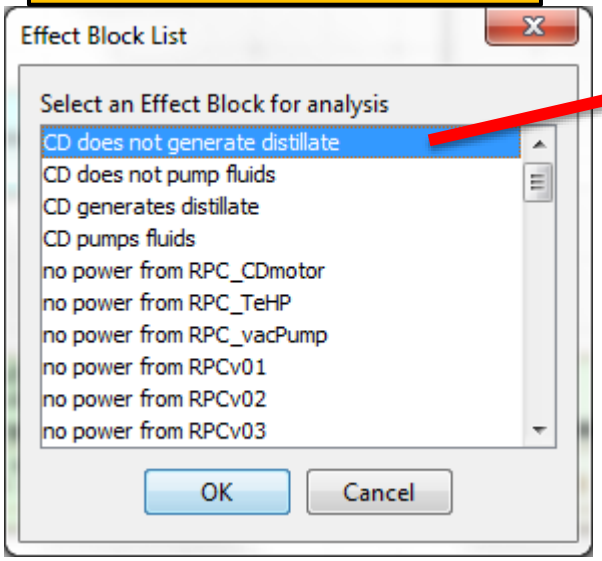
LRU/ Assembly Name	Item Name	Item Function	Potential Failure Mode	Effect				CRIT LEVEL	Potential Causes
				Immediate Failure Effect	End Effect	Number of Independent Failures	Other Independent Failures		
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Int Structure_Failure
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD pumps fluids	1		3	Loss of Magnetic Field
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to vacuum		1		4	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to		1		4	SpringFailure

FTA (Fault Tree Analysis) Extraction Tool

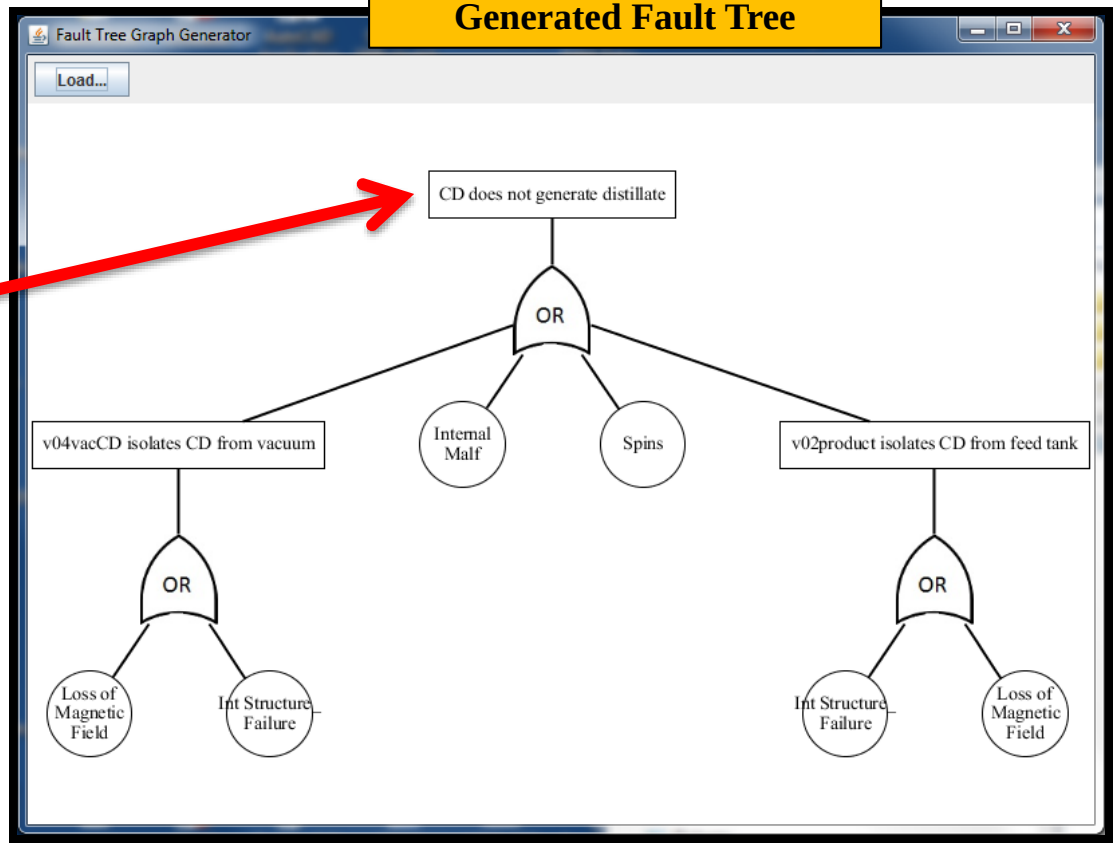
Magic Draw Plug-Ins



Select Top Level Event from Model to Analyze



Generated Fault Tree



Conclusion and Forward Work

Conclusion:

- A combination of education and outreach, institutional support, and a set of modeling guidelines and tools, has been successfully applied to multiple projects at JSC
- These initial successes are showing the path to the generalized adoption of MBSE
- Benefits of MBSE adoption include:
  - Significant time and effort savings to generate the operational products
  - Providing a single source of knowledge with the latest system configuration
  - Improving communication between multiple disciplines such as software, hardware, systems engineers, and CAD model developers

Forward Work:

- Continue to enhance the import tools to import data into the model from local sources used by multiple stakeholders (Visio, Power Point, CAD)
- Explore the development of flexible tools by leveraging the latest technologies in Ontology development and reasoning engines to enable the tools to be independent of the selected modeling method